THE INFLUENCE OF SITE AND AXIAL POSITION IN THE TREE ON THE DENSITY AND STRENGTH PROPERTIES OF THE WOOD OF *PTERYGOTA MACROCARPA* K. SCHUM

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ABSTRACT

Static bending, compressive, shear and impact bending strengths and density of Pterygota macrocarpa (Kyere) were investigated using small clear wood specimens from three sites in the Moist Semi-Deciduous (North-West) forest type, Moist Semi-Deciduous (South-East) forest type and the Dry Semi-Deciduous (fire Zone) forest type.

The results show that height positions of samples in a stem significantly affected wood density, bending, compressive, shear and impact strengths as well as modulus of elasticity. Wood density and mechanical properties decreased from the butt to the top of the stem indicating that wood samples from the crown area of a tree have lower strength properties. For example, mean densities of 670kg/m^3, 640kg/m^3 and 620kg/m^3 were obtained for the butt, middle and top logs respectively and mean compressive strengths parallel to the grain of 66.12N/mm^2, 59.46N/mm^2 and 51.60N/mm^2 were also obtained for the butt, middle and top logs respectively.

The basic and grade stresses derived for the wood indicate that it may be classified to lie between structural strength classes SC5 and SC6 of BS 5756 (1980). The grade stresses for wood from the different height positions also indicate that they all lie between classes SC5 and SC6 of BS 5756 (1980).

Density and mechanical properties of the wood of Kyere, with the exception of bending strength, also differed significantly with site. Wood samples collected from the site with the highest mean annual rainfall had the least density and strength properties. For example, whereas mean density of 630kg/m^3 was obtained for samples from Amantia, mean densities of 660kg/m^3 and 640kg/m^3 were obtained for samples from Akota and Abofour respectively. In the case of compressive strength parallel to the grain also, a mean value of 56.24N/mm^2 was obtained for samples from Amantia whilst mean values of 60.68N/mm^2 were obtained for samples from Akota and Abofour respectively.

Keywords: Pterygota macrocarpa, site, mechanical properties density.

INTRODUCTION

With the growing concern among foresters and environmentalists about the steady decline of the tropical rain forests, the need to make better use of materials from the existing forests cannot be over-emphasized. Methods of extraction that ensure that less material is left to go to waste in the forest, in the form of stem tops (top billets), branches etc., are continuously being sought.

An assessment of logging residues in three forests in Ghana indicated that branch wood could reach up to 90cm in diameter and that branch wood volume alone accounted for about 30% of the total tree volume and 60% of the logging residue (Adam et al. 1993).

Traditional logging and wood utilization practices, which appear to assume that the resource base is inexhaustible, must give way to more efficient methods.

Among the reasons usually given for not extracting timber from the crown area of trees is the lack of knowledge on the wood quality, which include density and mechanical properties. Within the same tree, in many species, significant variations in density are said to exist from the bark to the pith and up the trunk from the base (Kollman and Cote, 1968; Gyamfi, 1994). Variations in density throughout a particular cross-section of the stem are however said to be less pronounced than those along the height (Kollman and Cote, 1968).

Decrease in density from the base upward is the most commonly reported trend of variation in conifers, and appears to be typical of the pines (Panshin and Zeeuw, 1970). In hardwoods, although a similar trend has been shown to exist in some species, other reports of variation in density along the axes of stems indicate a variety of patterns within a species (Panshin and Zeeuw, 1970). Data on variation of bending, compressive, tensile, shear and impact strengths as well as modulus of elasticity with position in the tree are rather sparse. However, all the evidence available confirm that these variations are also reflections of the structural changes, and amounts and distribution of the tissues within the tree (Panshin and Zeeuw, 1970).

Wood characteristics are mainly the results of varying growth processes and differences in genetic constitution of different trees. Therefore any factor that affect the growth pattern of a tree may also affect its wood properties (Smith, 1988; Zobel and Talbert, 1991; Tsoumis, 1991). Whether trees grow on sandy or clay soils, under short or long growing seasons, or are subjected to major and differing environmental variations, some effect of environment on wood quality is to be expected (Zobel and Talbert, 1991). In a number of studies involving several species, differences in densities of samples from different geographic areas have been found (Howe, 1974; Talbert and Jett, 1981). Drier regions have also been found to produce wood of higher density in tropical hardwoods (Tsoumis, 1991).

The objective of this study therefore was to investigate how wood density and mechanical properties vary along the tree height from the butt to the top and also from one site to the other.

MATERIALS AND METHODS

Sample sites and conditions

Pterygota macrocarpa is a pioneer, light demanding and drought resisting tree and grows in the tropical deciduous forests of Africa and Asia (Irvine, 1961). Samples used for the investigation were obtained from three different sites in the semi-deciduous forest formations of Ghana - Amantia, Abofour and Akota (Figure 1).

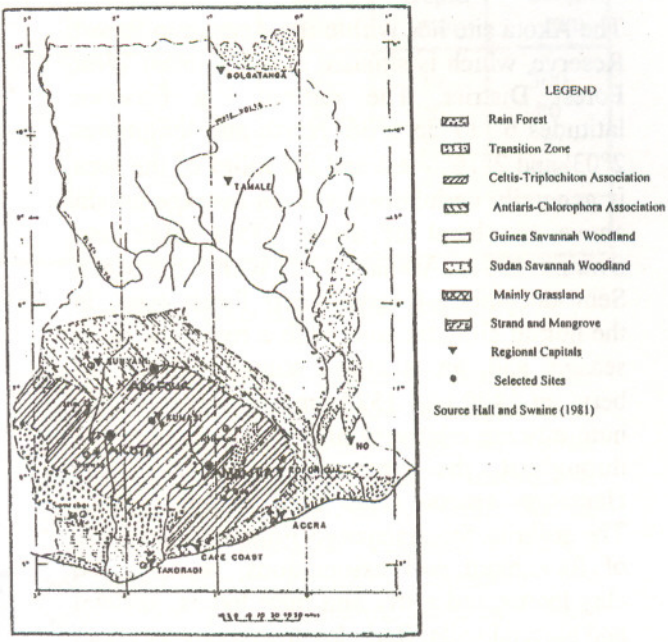

Fig.1 Forest Zones in Ghana Showing Sample Sites.

The Abofour site lies in the Afram Headwaters Forest Reserve, which is between latitudes 7°00' to 7°15' North and longitudes 1°32 to 1°48' West. The area is said to form a relief plateau between 274m and 411m above sea level and lies within the Dry Semi-Deciduous (Fire Zone) forest type (Hall and Swaine, 1981)., It is characterized by pronounced seasonally with a mean annual rainfall of about 1250mm (Hall and Swaine, 1981). The soil formation in the Afram Headwaters Forest Reserve is the upper and lower Birrimian rocks, granites and upper Voltaian sandstones which give rise to forest orchrosols and lithosols, with forest gleisols along riparian areas (Hall and Swaine, 1981).

The Amantia site, in the Pra-Anum Forest Reserve, however, lies in the Oda Forest District. The reserve is between latitudes 6° 11' to 6° 20' North and longitude 1°07' to 1°16' West. The topography of the site is gently undulating with an average height of about 190m. The site is situated within the Moist Semi-deciduous (South-East) forest type, with a mean annual rainfall of between 1500mm and 1750mm, characterized by a two peak rainy season and a mild Harmattan (Hall and Swaine, 1981). The soils of Pra-Anum are mainly composed of forest oxysol-ochrosol integrates.

The Akota site lies within the Asenanyo Forest Reserve, which is situated in the Kumasi West Forest District. The reserve lies between latitudes 6° 17' to 6°36' North and longitudes 2°03' and 2°16' West and the relief of the area is generally undulating with an average height above sea level of about 175m (Hall and Swaine, 1981). Asenanyo lies within the Moist Semi-deciduous (North-West) forest type, in the humid climatic zone with a two peak rainy season and an average annual rainfall of between 1400 and 1525mm. Temperature and humidity are relatively high and quite constant throughout the year, except during the Hamattan season (Hall and Swaine, 1981). The soils in the Asenanyo Forest Reserve are of four main soil associations, namely; red clay loams, red gritty and light loams, skeletal and alluvial soils. Red clay loams covers about 68% of the reserve area and are found on gentle undulations. Red gritty and light loams characterize gentle slopes, while mature and skeletal soils cover the Sumtwitwi Range with alluvial soils being only sparingly present on river terraces and flood plains (Hall and Swaine, 1981).

Samples Collection and Preparation

Three tree samples each of about 2.5m girth at breast height (ie. 1m height above ground level) and of average height of about 25m were randomly selected and felled at each of the three sites. From each tree sample, three billets each of about 2m length were cut - the first billet from the butt end (about 1m above ground level), a middle billet about 7m from the butt end and a top billet about 14m from the butt end. Thus, in all, 27 billets from nine tree samples were collected from three sites. From each billet, planks of 55mm thickness, 105mm width and 2000mm length were sawn along the radial direction beginning from the pith after removal of the sapwood (Figure 2). These were subsequently staked for air-drying under a shed to average moisture content of about 14%.

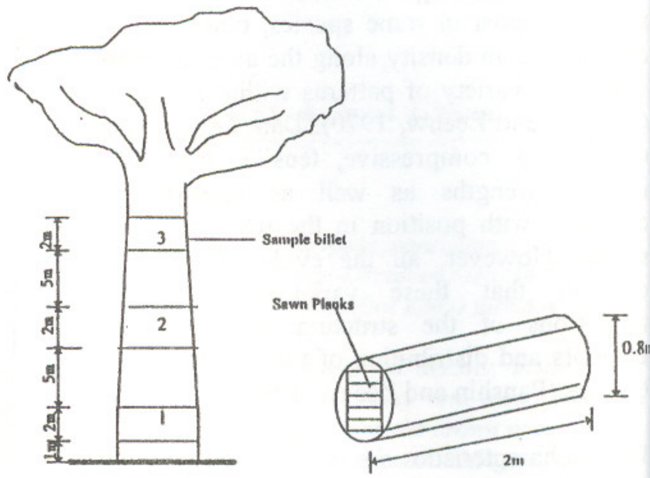

Fig.2 Showing Sample Cutting Principles

Samples of the air-dried planks were cut into 25mm x 25mm x 1000mm strips and subsequently planed and dressed into 20mm x 20mm x 1000mm strips which were then cut into test specimens lengths in accordance with DIN 52180 (1977) Part 1. A total of 2,160 specimens were tested.

Determination of some physical and mechanical properties of the wood

Specimens for static bending were tested in accordance with DIN 52186 (1978) and those for compression parallel to the grain in accordance with DIN 52185 (1976). Shear and impact bending test specimens were tested in accordance with DIN 52187 and BS 373:1957 respectively. A 5000kg Universal testing machine was used for testing the specimens in static bending, compression and shear whilst a 4000kg Amlser machine was used for testing impact bending strength.

Density and moisture content were also determined in accordance with DIN 52182 (1976) and DIN 52183 (1977) respectively.

Table 1: Test programme and dimensions of specimens

Property	No.of Specimens per Site	No. of Specimens per Tree	Total No. of specimens	Width mm	Depth mm	Length mm
Static bending	180	60	540	20	20	300
Compression	180	60	540	20	20	80
Shear	180	60	540	20	20	20
Impact bending	180	60	540	20	20	300
Total	720	-	2160	-	-	-

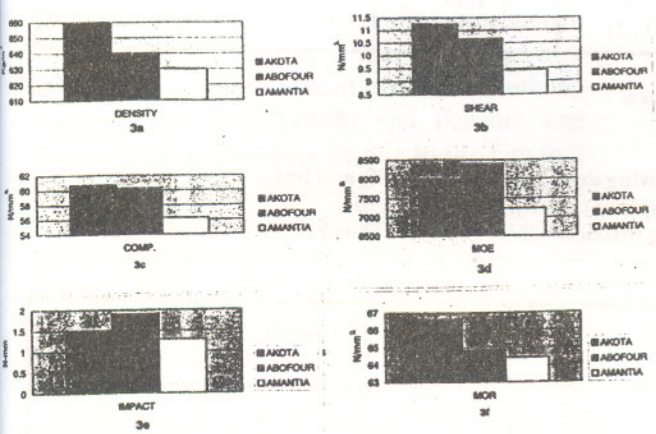

Fig.3. Comparative densities (a), shear strengths (b), comparative strengths (c), modulus of elastically (d) impact strength and modulus of rupture (f) of P. macrocarpa from Akota, Abofour and Amantia.

STATISTICAL ANALYSIS

An analysis of variance (ANOVA) was done using SYSTAT V5.0 (Statistical and Graphical Analysis Package), to determine whether any significant differences existed between properties of the wood samples from the different axial positions along the tree and also from the different geographical locations of the sites. A post hoc test using Tukey's Multiple Comparison was subsequently done to test which of the sites and height positions were actually different.

RESULTS AND DISCUSSION

Mean values of all properties tested were calculated for the butt, middle and boles of all tree samples from the different sites. Comparative densities and mechanical properties of *P. macrocarpa* from Akota, Abofour and Amantia are presented in Table 2 and graphically in Figure 3. Laboratory test values at 14% moisture content were converted to 12% using the formula suggested by Bodig and Jayne (1982) and the basic and grade stresses derived for the wood from the butt, middle and top logs as well as for the overall mean strength values (Table 6), in accordance with the methods used by Both and Reece (1969) and Keating (1985). Grade stresses for the structural strength classes SC5 and SC6 BS 5756 (1980) were included in Table 6 for comparison.

The ANOVA shown in Table 1 indicates that all the wood properties tested, except modulus of rupture (MOR), differed significantly ($P = 0.05$) with site. Site-height interaction was significant for only MOE, compression and impact bending strengths (Table 1) suggesting that these three mechanical wood properties are likely to be higher in trees growing on sites with the lowest growth enhancing potential. The values of the physical and mechanical properties of the wood samples from Akota and Abofour sites are higher than those for samples from Amantia (Fig. 3 and Table 2). Samples from Akota have the highest density, compressive and shear strengths followed by those from Abofour. In the case of MOE and impact strength, however, samples from Abofour were superior to those from Akota.

Table 2: Mean densities and strength properties of the wood of *P. macrocarpa* from three sites at 14% moisture content

Wood Properties	Amantia Site	Akota Site	Abofour Site	Overall mean for three sites
Density kg/m$_3$	630 (80)	660 (20)	640 (80)	640 (60)
Shear strength N/mm^2	9.43 (1.65)	11.24 (1.95)	10.67 (1.83)	10.45 (1.81)
Comp. strength N/mm^2	56.24 (8.26)	60.68 (10.06)	60.30 (8.96)	59.07 (9.10)
Modulus of Rupture N/mm^2	64.43 (9.00)	66.62 (10.90)	64.84 (9.65)	65.30 (9.85)
Modulus of Elasticity N/mm^2	7230 (1285)	7984 (1665)	9390 (1520)	8201 (1490)
Impact strength N-mm	1.29 (0.33)	1.50 (0.22)	1.90 (0.22)	1.56 (0.25)

Values in brackets are the standard deviations of the mean values.

Table 3: Two-way analyses of variance (ANOVA) table showing degrees of freedom (df) and test statistics (F) of modulus of elasticity (MOE), modulus of rupture (MOR), shear strength (SHEAR), Compressive strength (COMP), Impact Bending Strength (IMPACT) and Wood Density (DENSITY) of *P. macrocarpa*.

Source of variation	df	MOE F	MOR F	SHEAR F	COMP. F	IMPACT F	DENSITY F
Site	2	31.58	2.98n.s	60.02 20.83	11.78	58.30	5.48
Height Position	2	7.07	28.55	0.09n.s	13.13	5.14	14.58
Site* Height	4	2.67	18.15		0.70	10.01	1.48n.s
Error	531						

n.s means not significant at 5% level of probability.

The physical and mechanical properties of samples from the butt end of the stem of *P. macrocarpa* appears to be significantly higher ($P = 0.05$) than wood samples collected from the middle and top parts of the stem (Table 3).

Table 4: Tukey's Multiple comparisons of mean properties of *P. macrocarpa*

Property Site	MOE	MOR	SHEAR	COMPRESSION	IMPACT	DENSITY
Amantia	7230a	64.43a	9.43a	56.24a	1.29a	630a
Akota	7984b	66.62a	11.24b	60.68b	1.50a	660b
Abofour	8390b	64.84a	10.67b	60.30b	1.90b	640c

Similar letters indicate no significant difference between two sites.

Table 5: Tukey's multiple comparisons of mean properties of samples along the stem from butt to crown

Property Height position	MOE	MOR	SHEAR	COMPRESSION	IMPACT	DENSITY
Butt	8492a	71.07a	10.99a	66.12a	1.91a	0.67a
Middle	7390b	62.46b	10.62a	59.46b	1.50b	0.64b
Top	7722b	62.45a	9.73b	51.60c	1.28b	0.62c

Similar letters indicate no significant difference between two sites.

The test results generally show that samples from the butt have greater density and strength properties followed by the middle and the top billets respectively.

The variation in density and mechanical properties along the tree height from thee butt to the top, is in agreement with the work by Kollman and Cote (1968) and Panshin and Zeeuw (1970). This may be due to the fact that the butt log of the same tree has more mature wood than the top log which consists mainly of juvenile wood (Stern, 1963; Panshin and Zeeuw, 1970: Zobel et al., 1972). Juvenile wood is explained by Kolzlowski (1971) and Larson (1969) as being the results of the relative abundance of growth regulators and carbohydrates in the cambial zone near the crown. Juvenile wood density is lower than that of mature wood. The lower density and strength properties (ie. bending, compressive, shear and impact bending strengths) of the wood near the top may be due to the thin walls of the cells of the wood, the lower cellulose content and crystallinity of the wood compared with that of the matured wood in the log at the butt" (Zobel and Talbert, 1991; Tsoumis, 1991). The reduction in density and strength properties with the logs (Zobel and Talbert, 1991; Tsoumis, 1991). The reduction in density and strength properties with the axial position in a tree may also be due to mechanical factor. From the mechanical point of view, the trunk of a growing tree is considered a cantilever. Under the influence of weight, wind acting on the crown, grater stress develops at the base resulting in formation of wood of higher density and higher strength (Tsoumis, 1991). Genetic factors may also be responsible for the within tree variation in density and strength properties (Tsoumis, 1991).

The overall mean grade stresses derived indicated that the wood of *P. macrocarpa* may be classified to lie between structural strength class SC5 and SC6 of BS 5756 (1980).

Table 6: Basic and stresses of *P. macrocarpa* at 12% moisture content

Property	Butt wood	Middle Wood	Top Wood	Mean stress	Grade stress SC5	Grade stress SC6
Basic bending stress Grade Stress	23.73 11.39	20.85 10.50	20.85 9.50	21.80 10.46	10.00	12.50
basic comp. stress Grade stress	34.70 16.66	31.20 14.98	27.08 13.00	31.00 14.88	8.70	12.50
Basic shear stress Grade stress	3.26 1.57	3.15 1.51	2.89 1.39	3.10 1.49	1.00	1.50

Data on structural strength classes SC5 and SC6 were taken from BS 5756 (1980).

The grade stresses derived for the tree axial positions also indicate that the wood from these position all lie within the same structural strength classes SC5 and SC6 (Table 6). Thus although there were significant differences between the laboratory test results for properties of the wood from the different height positions, they may be used for the same structural application.

The lower strength properties of wood from Amantia compared to the other sites may be attributed to differences in micro-environments at the three sites. The rather significantly lower density and mechanical properties of samples from Amantia compared to the other two sites is probably due to the relatively higher mean annual rainfall at Amantia than the other sites. The Amantia site in the Moist Semi-Deciduous (South-East) forest type has the highest mean annual rainfall of between 1500mm and 1750mm, while Akota and Abofour have mean annual rainfall of between 1250mm and 1500mm. The comparatively higher mean annual rainfall at Amantia may have resulted in increased growth rate, producing wood with high proportion of early wood. This contains wood cells with thin cell walls and large lumens and wood fibres do not sufficiently overlap each other to enable adequate transfer of applied loads. Such wood therefore has low density and strength properties. The variations in density and mechanical properties with site may also be due to age differences between trees sampled from the different sites. Thus, even though trees of about the same sizes were sampled, favourable growth conditions at one site such as Amantia might have enhanced the growth of young trees and resulted in the reduced density and mechanical properties. Aside from environmental factors, a significant factor for the variations might be differences in genetic constitutions of the different trees from the different sites (Tsoumis, 1991).

Soil conditions at the sample sites may also have played a significant part in the trend of the wood properties. This is due to the fact that on the basis of rainfall alone, samples from the Abofour site in the Dry Semi-deciduous forest type, with the least mean annual rainfall of 1250mm, would have been expected to have superior density and strength to those from Akota in the Moist Semi-Deciduous (North-West) forest type, with mean annual rainfall of between 1400mm and 1525mm. Information available on the soil formation at the three sites (Hall and Swaine, 1981), indicates that the soil formation at the Abofour site is the forest ochrosols and lithosols with forest gleisols along riparian areas. Its is comparatively more fertile than that at the Akota and Amantia sites and therefore might have resulted in fast tree growth and reduced density and mechanical properties. The soil fertilities of the Akota and Amantia sites are, however, reported to are similar (Hall and Swaine, 1981). Bush fires attack of trees in the Dry Semi-Deciduous (Fire Zone) forest, in which the Abofour site is located, may also be responsible for a reduction in mechanical properties. Fire attack of growing trees may have adversely affected wood cells development and the structure of the wood and hence the wood density. Since the strength of wood is closely related to its density, this may explain why the shear strength, compressive strength and the modulus of rupture of the wood samples from the Akota site were higher than those from the Abofour site. The wood samples from the Abofour site were, however, stronger in stiffness and impact resistance than those from the other two sites (see Table 2).

CONCLUSION

The results of the within tree variation shown by this experiment have indicated that sampling heights are of importance to any studies related to wood qualities of tropical hardwoods. A proper determination of wood characteristics of a tree should involve samples along the whole tree height.

The results of the investigation have shown that wood samples from the top part of a tree, have lower density and strength properties compared with those from the lower parts of the tree. Due to its low strength properties, juvenile wood from the crown area is weak when used as a solid wood product (Pearson and Gilmore, 1980). Grade stresses derived for wood from the different height positions indicate that wood from these positions may be used for the same structural purpose. The wood from the crown area may be used for structural applications, however, due consideration should be given to the fact that juvenile wood distorts when dried. It shrinks longitudinally much more than does mature wood. The instability is said to be the result of relatively flat fibril angles and causes major problems on drying (Meylan, 1968).

Sites from which tree samples were collected have also been shown the results to affect the density and chemical properties of the wood. Thus when sampling for the characterization of the properties of wood species, as many sites as possible should be covered to obtain more representative values. Due consideration should also given to this issue when designing structural timber members using species which are widely distributed.

REFERENCES

Adam, A.R., Ofosu-Asiedu, A., Dei-Amoah, C. and **Asante-Asiamah, A**. (1993). Wood waste and logging damage in Asukese and Afram Headwaters Forest Reserves, Ghana. Report of ITTO Project PD 74/90 "Better utilization of Tropical Timber Resources in order to improve sustainability and reduce negative ecological impacts, FORIG, Kumasi. P.46-51.

Bodig, J. and **Jayne, B.A.** (1982). Mechanics of wood and wood composites. VNR Publishers, New York. Pp 551-557.

Both, L.G. and **Reece, P.O.** (1967). The structural use of timber. A commentary on the standard code of practice CP 112.SPON, London. Pp.551-557.

British Standards Institution (1980). Specifications for Tropical hardwoods graded for structural application. British Standards B.S5756 (1980), London. Pp 1-4.

British Standards Institution (1957). Methods of testing small clear specimens of timber. BS 373: 1957. P. 7-8.

DIN52186 (1978). Prufung von Holz. Biegeversuche - "Testing of wood. Bending Tests".

DIN52183 (1977). Bestimmung des Feutigskeitgehaltes - "Determination of moisture content".

DIN52180 (1977). Teil 1: Prufung von Holz. Probenahme, Grundlagen - Testing of wood. Sampling and cutting, principles.

DIN52185 (1976). Bestimmung der Druckferstigskeit in Fasserrichtung - "Determination of compressive strength parallel to the grain".

DIN52182 (1976). Prufung von Holz. Bestimmung der Rohdichte - "Testing of wood. Determination of density".

Gyamfi, C.K. and **Breese, M.C.** (1994). Some mechanical properties of *Amphimas pterocarpoides*. Part of M.Sc. Degree Thesis work conducted at Wood Sci. Dept. University of Wales, Bangor, U.K. (Unpublished). P. 3-8.

Hall, J.B. and **Swaine, M.D.** (1981). Geobotany 1. Distribution and ecology of Vascular Plants in a tropical rain forest. Forest vegetation of Ghana. Dr. W. Junk Publishers. The Hague - Boston - London. P. 1928.

Howe, J.P (1974). Relationship of climate to the specific gravity of four Costa Rican Hardwoods. Wood fiber 5(4): 347-352.

Irvine, F.R. (1961). Woody Plants of Ghana. Oxford University Press. P. 355-357.

Kollman, F.P. and **Cote, W.A.** (1968). Principles of wood science and technology 1. Solid wood. Springler-Verlag. Berlin. P. 168-171.

Kolzlowski, T.T. (1971). Growth and development of trees, Vol. II. Academic Press, New York. P. 86.

Larson, P.R. (1969). "Wood formation and concept of wood quality. Bulletin No. 74, Yale University School of Forestry, New Haven.